Chapter Four

Data acquisition and processing

4.1 Introduction

The manner in which an experiment can be planned and executed to produce meaningful data. Selection of proper instrumentation and consideration of experimental uncertainties are all necessary parts of the planning process. But very little has been said about the manner of collecting data and the later processing of these data to produce the desired results of the experiments. The acquisition of data might consist simply of several people (or perhaps only one person) reading a number of instruments and recording the observations on a data sheet. The subsequent processing of data could be done in many ways, from simple hand calculations to complicated computer routines.

There are systems available today for rapidly collecting a great bulk of data, processing it, and displaying the desired results in printed form. The purpose of this chapter is to present a brief qualitative description of such systems and the functions of the elements that go together to make up an overall data acquisition and processing installation. These systems change rapidly.

4.2 The General Data Acquisition System

The essential element in a data acquisition system is the instrument transducer, which furnishes an electrical signal that is indicative of the physical variable being measured. The signal may be an analog voltage, current, resistance, or frequency, or a digital representation of any of these quantities in the form of a series of electric pulses. The present discussion assumes that suitable transducers are available to convert the physical variables of interest into electrical signals. As examples of such transducers we may recall that a thermocouple gives a voltage representation of temperature, a strain gage gives a resistance representation of strain, and so forth.

The object of any data acquisition and processing system is to collect the data, process them in the desired fashion, and record the results in a form suitable for storage, presentation, or additional subsequent processing. Thus, a recording potentiometer is a simple data acquisition system that may be used for collecting temperature data from thermocouples. In this case the data points must be read from the recorder chart. A more complicated system would convert the analog voltage signal from the thermocouple to an equivalent digital signal, which could be used to operate a printing recorder so that the numerical value of the temperature is printed on a sheet of paper. Such a system is much more complicated than the simple recorder because of the analog-to-digital conversion process. It is easy to see, however, that the digital output has many advantages.

The major elements of any data acquisition and processing system are shown in the following Figure. This figure divides the system into three major parts. The first is the input stage, which consists of appropriate transducers and an input circuit and additional signal conditioning circuits as needed (amplifiers, filters, etc.). The second is the signal-conversion stage, in which the information is readied for transmission, if such is required (as in situations in which the transducers are physically remote from the location at which data display is desired), as well as the transmission and receiving equipment and any necessary data processors. An example of the latter would be the conversion of a signal from analog-to-digital (A/D) form. The last is an output stage which provides two primary functions: data display and data storage. Examples include data display and storage in printed form on a sheet of paper or in graphical form on suitable paper and storage on magnetic tapes or disks, or in the internal memory of a computer.

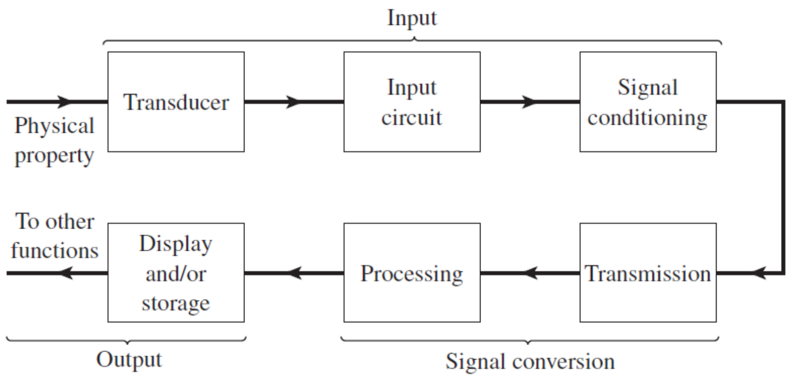

Figure 4-1. General data acquisition system.

The output stage must include suitable coupling circuits to convert the data to a form which may be used to drive a printer, graphics device, or computer processing unit.

It is a rare circumstance when data involving only one experimental variable are to be collected. The data acquisition and processing system, then, should include provision for collecting and analyzing multiple channels of data input. This collection process could be accomplished by having a channel like the one shown in Fig. 14.1 for each variable to be studied. The cost of such a system, however, would be quite high because of equipment duplication so that a scanner/programmer is normally employed for multiple-channel work. The scanner is a device that samples the data channels in rapid sequence so that only one conversion and output stage is necessary. Equipment available today makes possible any particular sequencing of a large number of data channels at the discretion of the laboratory personnel. Thus, the system may be programmed to collect any desired range of variables in any order, and the term "scanner/programmer" is quite appropriate. In many systems computational elements are provided in order that the data may be manipulated immediately, without external computer processing.

Many experimental situations require the collection of data at regular time intervals or in some particular time sequence. The acquisition system may perform this timing function automatically by incorporating a digital clock and time standard in the scanner and/or conversion stages.

Finally, it may be advantageous to apply signal conditioning to the output of the device functioning as the scanner/programmer. This conditioning might be amplification, analog-to-digital conversion for only some of the channels, filtering, distortion or harmonic analysis of the waveform of some of the signals, and so forth. When all the above elements are combined, a very flexible data acquisition and processing system results, as shown in the following Figure. It should be noted that the programmable feature of the scanner is normally used in the converter stage as well. This is essential since some channels may require signal conditioning while others may not.

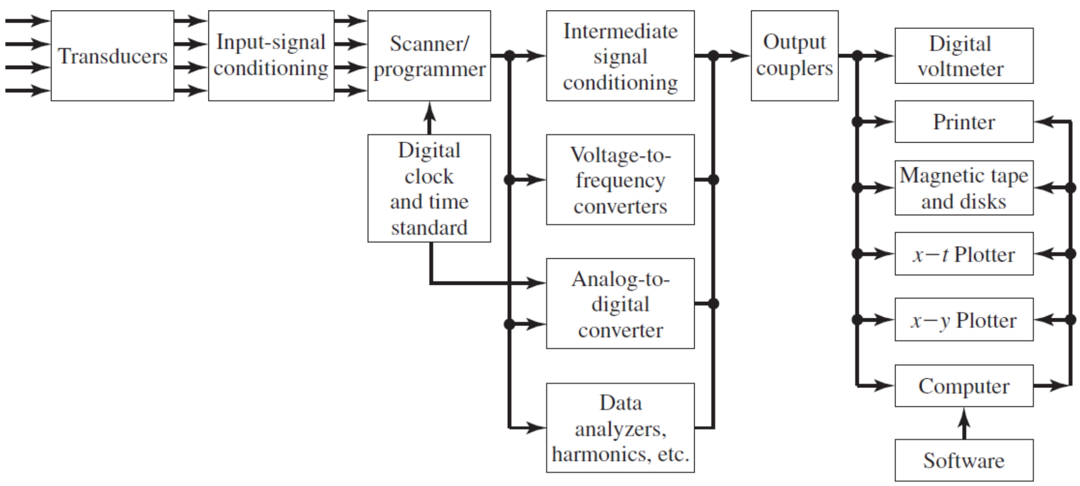

Figure 4-2. Schematic of a multichannel data acquisition system.

The use of a flexible system like the one described above depends on many factors, not the least of which is cost. Progress in the development of microprocessors and digital signal processing (DSP) [1, 4, 6, 8] has greatly reduced the cost of such systems. Data acquisition processing systems which use microprocessors to perform the scanner/programmer function are widespread. We note that the general system may be used to feed a computer, which, in turn, has a software input to process the data or cause the computer to execute some process control operation. The output from the computer can also be fed to a printer for either text or graphical displays. Many standard software packages are available to perform the computer operations.

There are two basic types of interfaces to connect the measurement system to a personal computer: stand alone and plug in. The plug-in systems are designed for a particular type of computer. The plug-ins consist of special terminal boards for connection of thermocouples, RTDs, or other sensors and outputs. Menu-driven software is included which enables a setup of scale ranges, units, digital input and output, data logging, and process control for any of the channels. Hundreds, or even thousands, of analog inputs can be allowed for a single PC. The stand-alone interface does not depend on the type of computer to be used. All that is required is a standard serial communications port on the computer. The stand-alone interfaces can incorporate a single-variable channel, multiple thermocouples, or many channel data loggers with different analog inputs. Stand alone may or may not be supplied with software capability. If not supplied, then the user must provide his/her own software. In general, a variety of software packages are available from many manufacturers.

Some data acquisition systems have on-board microprocessors for data analysis and storage. Depending on the complexity of the system, it may be possible to analyze some data channels while storing the output of others for later manipulation. Because of the reduction in cost of memory devices, we may expect very elaborate data acquisitions systems in the future which incorporate digital oscilloscope features in one central processing unit. Cost will be a factor in decisions to utilize such systems.

4.3 Data storage and display

Data storage and data display do not always require different apparatus. The relatively simple methods of data display often provide simultaneous storage. Examples include the *xy* plotter, the strip-chart recorder, paper tape output from a calculator or a computer, and even the recording of experimental data by pen in a notebook. The data are both displayed and stored in all these cases. A storage oscilloscope also provides a dual function because in such a device there is at least temporary storage of the data for as long as the instrument is left on.

There are also devices which are intended to provide only a storage function. Such storage media are most useful if the data stored are easily retrievable for display or subsequent processing. As an example, let us consider the problem NASA has in transmitting television pictures to earth from deep-space probes. Normally, the images "seen" by the cameras are stored in digital form in memory devices on board the craft. When a transmission is made to earth, the stored data are sent, bit by bit, using appropriate coding techniques, to earth, where the received information is again stored on magnetic devices. This information is digitally filtered to reduce the effects of noise, and the resulting image is printed. In addition to magnetic tape, other forms of more or less permanent storage are CDs, magnetic cores, magnetic disks, and various kinds of semiconductor memories. Semiconductor memories are of both the permanent and volatile type. Stored information in the latter type may be lost if the power is removed.

4.4 The Program as a Substitute for Wired Logic

The general data acquisition system serves many functions. In addition to gathering, processing, storing, and displaying data, it often is required to perform a control function. In the case of a nuclear power plant an indication in the data acquisition system that a nuclear core temperature is exceeding some operational limit will result in an automatic shutdown of the nuclear reaction. The entire data acquisition and control system must be able to make logical judgments. It is expected that this system will be backed up by human judgment as well, but for maximum safety the electronic system itself must be capable of such decisions. How is the control function fulfilled? A simple schematic answer is presented in the following Figure. This sketch shows the familiar elements of a transducer and the subsequent data acquisition and display functions. In addition, there is a new element in which a decision is made electronically. In this module the question, “Is the temperature T

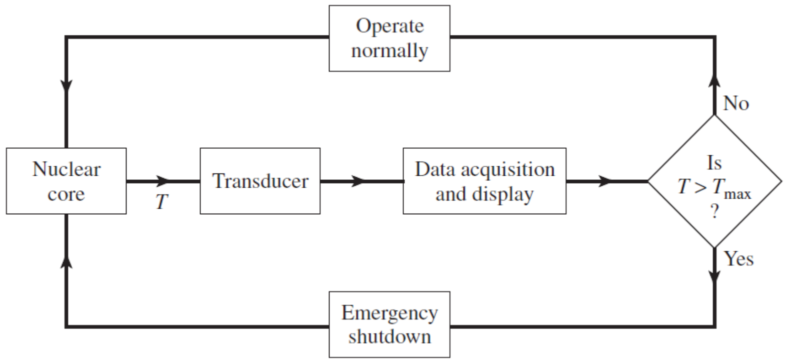

Figure 4-3. Program substitute for wired logic.

greater than the safe operating temperature T_{max}?” is electronically answered. If the answer is “yes,” the system generates an electronic signal which begins an automatic emergency shutdown of the nuclear reaction. If “no,” the system indicates that all is well and allows the core to continue to operate.

In order to implement this logical decision-making process a single integrated circuit called a Schmitt trigger may be used. The threshold voltage VT can be electrically controlled. This voltage is set to be the voltage produced by the transducer as shown above when the nuclear core temperature is equal to T_{max}. As long as the actual temperature is below this value, the voltage output of the Schmitt trigger will be zero. Once the safe operating temperature limit is exceeded, the Schmitt trigger will have a positive voltage at its output, and this voltage may be fed, through appropriate interface circuitry, to the equipment which initiates the emergency shutdown procedure. This example illustrates a segment of electrical engineering known as *logic design*.

As an example of a reasonably simple logic design problem, let us consider the task of preparing a circuit which will monitor a traffic control signal and generate an error message when an illegal combination of lights appears. This signal could be routed to maintenance headquarters to alert the staff to the existence of a traffic signal problem. In the state in which this is being written legal light combinations are red only, yellow only, green only, and red-yellow together. All others are illegal. The following Figure illustrates the solution to this problem in the form of a block diagram. It should be noted that error messages occur whenever three or no lamps are lit as well as when any two lamps other than red-yellow are lit. In any of these cases an error signal must be generated as indicated in the diagram. The logical processing shown in this problem can be carried out by means of digital logic circuits. To illustrate this briefly, imagine that we have available three electrical wires; the first of these will be at a positive voltage if the red lamp is lit and 0 V if the red lamp is out, the second line is tied to the yellow lamp, and the third is tied to the green lamp in analogous fashion. In order to decide if all three lamps are on, a logical AND gate is used as sketched below. This gate will produce a positive output voltage only if each of the inputs is positive. In this case, an output will occur only if all three of the lamps are simultaneously lit. Since this is an error condition, this output signal could be used to generate the necessary error message. In an analogous fashion, other gates are used to check if any other error conditions exist. In addition to AND gates, there are other classes of digital logic circuits, and, indeed, the designing of circuits containing these decision-making gates is a separate area of study.

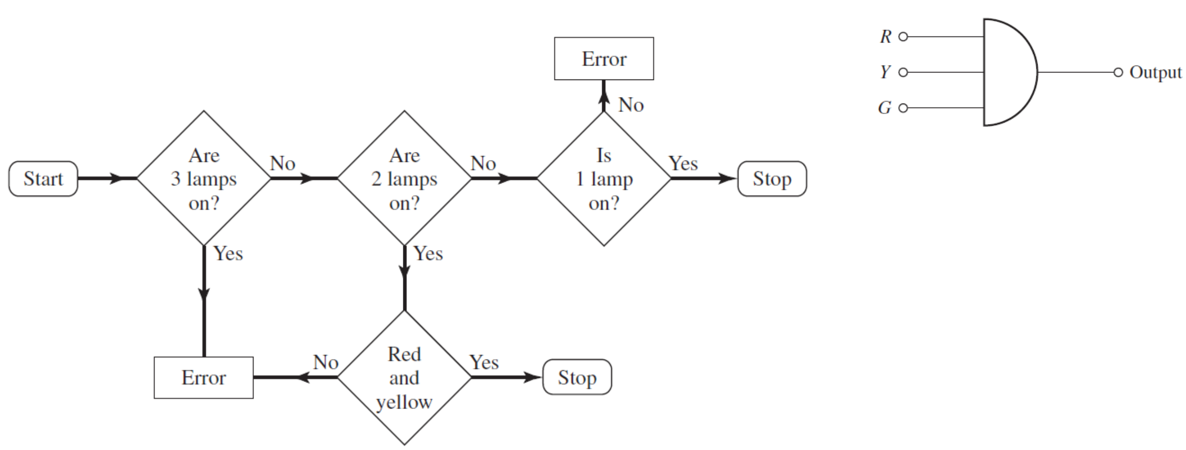

Figure 4-4. (Left) Logic for lamp circuit, (right) Logical AND gate.